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Territorial accessibility analysis as a key variable for diagnosis of urban mobility: A case study Manizales (Colombia)

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Abstract

Convenience analysis methodologies are employed in this article in order to assess territorial urban mobility. This paper is based on data collected over a period of time more than a year utilizing GPS devices. More than 18 million readings were collected corresponding to operational characteristics of car, taxi, motorcycle, truck and different modalities of public transport (UPT). The proposed methodology was applied through the mobility plan of the city of Manizales (Colombia) during the year of 2011. Manizales is a medium sized city with approximately 360.000 inhabitants, located in the central range of the Colombian mountains The average operating speed on each street network arc is the primary analysis variable; Geostatistical techniques are applied to predict the average travel time of each transportation mode . The results obtained are shown graphically and correspond to current city mobility data in a manner permitting comparison between transportation modes. It is concluded that the taxi mode of transportation with respect to accessibility provides better accessibility followed in corresponding order by motorcycle, car, truck and finally UPT; it has been determined that UPT provides the worst global accessibility media conditions; however, the UPT is the mode of transport most frequently used by the population (75% of daily trips).

Keywords: Accessibility; GPS; GIS; urban mobility; operating speed

1. Introduction

An accessibility analysis can technically demonstrate the potentials interaction between different geographical points (Izquierdo, 1994), defined as a measure of territorial ease of communication between human settlements or activities using a particular mode of transport (Morris et al., 1978; Zhu and Liu,

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2004). It also permits determination of ease or difficulty of reaching a destination via available infrastructure and means of transport, (Geurs and Ritsema van Eck, 2001). In general, accessibility is considered an important competiveness factor (Biehl, 1991), given that more accessible communities attained greater economic success over time.

The accessibility analysis plays an increasingly stronger role in the valuation of infrastructure strategies and projects taking into consideration that improved of accessibility are often one of the factors contemplated in such an evaluation (Gutierrez et al., 2010). Likewise, there are accessibility analyses that permit consideration of criteria, among other factors, related to economic development (Rietveld and Nijkamp, 1993; Vickerman et al., 1999; MacKinnon et al., 2008), demography (Kotavaara et al., 2011) and social cohesion (Schürman et al., 1997; López et al., 2008).

It is possible to establish that accessibility is closely related to the variable "distance", which becomes a function dependent on the proximity between an area and region's geographical points. However, it is reasonable to say, that given the current technological developments accessibility depends less and less on actual distance to activity centers and relies increasingly on the distances to transport infrastructures (Gutierrez, 1998) and on how such infrastructures shorten connection intervals in which cases the various modes of transport play a fundamental role in the analysis.

The Manizales transport infrastructure was updated for this paper and field work and office activities supported by aerial photographs of different areas of the city, in order to validate information entered in the GIS. The data was taken from the operational speed of different transport modes (car, taxi, motorcycle, truck and UPT) .

More than 18 million operating speeds readings were obtained and used to define the operational characteristics of the network. Operational speeds were calculated through monitoring actual data and show the real operational characteristics of the arcs that make up the network, which stands-out because, accessibility analysis usually assumes operational speeds, dependent on the route category (Burns, 2007). However recent accessibility researches exist based on actual vehicle speeds. (Li et al., 2011).

An important advantage in the use of GIS is that it facilitates understanding of networks performance (Gutierrez et al., 2010), analyzed through algorithms (e.g., minimum paths) that provide investigative simulation. The GIS has the ability to store large amounts of socio-economic and demographic information as well as information about the network's operational characteristics. This allows for relation between different levels of information leading to more detailed knowledge of accessibility features presented by the various modes of transport.

From the social perspective, it is important that people have access to typical social activities it being understood that greater social inclusion requires excellent accessibility which requires provision of adequate means of mobility through suitable transport systems (Farrington and Farrington, 2005).

This research determines that imbalance exists with respect accessibility offered through different modes of transport. For example, UPT, which offers the more number of urban trips per day, (75% of the total), provides appalling accessibility conditions. While with the smallest taxi mode of mobility percentage of daily urban travel (5%) provides the best accessibility conditions. It is obvious that not all people can afford the cost of taxi service or private cars. This situation points out the existing social imbalance that persons with limited financial resources have and that limits their possibilities of mobility.

After the introduction, in section 2, the methodology for calculations of accessibility is introduced, describing the creation of the employed database. Section 3 shows the main results and finally, section 4 deals with the main conclusions obtained.

2. Methodology

The research methodology referred to in the investigation comprises four stages: The first deals with preparation of complete whole transport infrastructure network, which in turn incorporates several sub stages, like requisition of data concerning the geo referenced network updating, and the determination of its operational characteristics; the second relates to calculations of arcs average operational speeds; the third is related to average Global accessibility calculations provided by the infrastructure's network in the different modes of transport studied; and the fourth stage concerns calculation of the percentages of areas, population and number of homes covered by the average travel time curves, stemming from accessibility analyses.

2.1. Updating and validation of the transport infrastructure network.

GPS devices were installed in different types of vehicles (car, taxi, motorcycle, truck and UPT), so as to store data from positioning satellites according to a predetermined (one second) time interval. Based on the type of vehicle in which the GPS was installed, a sequential number for each data item with its respective location (longitude and latitude) geo referenced and the hour-minutes-seconds and tenths of a second, was obtained. The accuracy of the GPS equipment was affected by the technology and number of satellites available, in our case of ±3 meters.

The infrastructure network is made up of nodes and arc aggregates (path segments), which are spatially located. Network Analysis consists of more than 12.000 arcs and over 9.000 nodes. Because of the high number of variables it was normal to find inconsistencies related to the information base: e.g. erroneous street classification flow paths, lack of arches, errors in the connections within the network, duplicate arcs, etc.

Figure 1 shows the overlap of some GPS data on two sections of the road network. It discloses vehicle route sequence, ensuring that the arc will not be displaced with respect to the data, often due to incorrect route data in the study graph, possibly due to reticular (flat) plotting information.

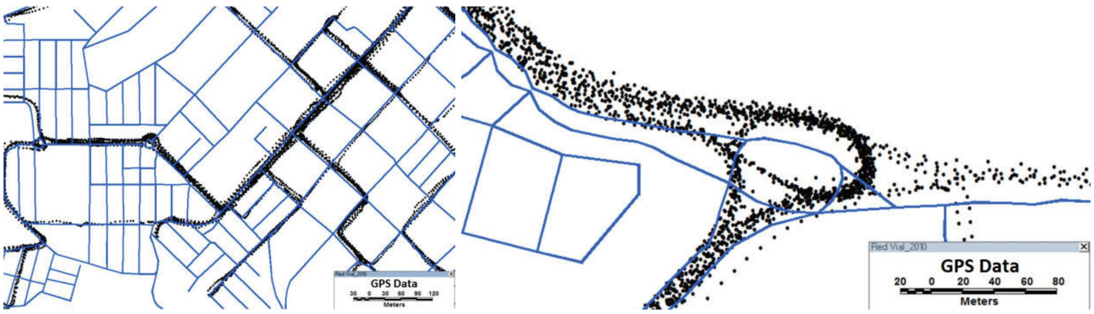


Fig. 1. (a) Superposition of the data from GPS data; (b) inconsistency with respect to the displacement of the network.

The process of validating the information consisted of verifying the database structure, the coordinate system, the time between data and information, the data stream, the format of the files, and the expected accuracy, etc. The identification of the sequence of data based on the foregoing variables for a specific of trip is a particularly complex process given that sometimes equipment temporarily loses the signal or receives inconsistent information.

In this sense, the use of control algorithms is particularly helpful for detecting inconsistencies in logically defined criteria, e.g., valuable sequences of known nodes and top speeds. Having used the most current transport infrastructure network information (year 2010) and overlapping the routes registered by the GPS equipment, some elements were found that required aerial photography or on spot validation.

2.2. Projections of Operational Speeds.

The processing of all the information required the application of different estimates according to the development of the project, putting special emphasis on the operational speed analysis because that variable determines the overall performance of the network and becomes a key element for accessibility forecasts (Geurs and Ritsema van Eck, 2001).

The operating speed for each graph was determined on the basis of the time data obtained on an ongoing basis by the GPS equipment. Three parameters were analyzed:

The operating speed per time interval between two points (Ec.1). This parameter is useful to establish variations of speed in a specific graph, and to determine the number of stops zero-like values are obtained, also referred to as the instantaneous vehicle speed. Where Vi = speed in Km/h; x_1, y_1 = coordinates of point 1 in meters; x_2,y_2 = coordinates of point 2 in meters; t = time interval in seconds between points 1 and 2.

$$v_i = \frac{3.6}{t}\sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} \qquad (1)$$

(Ec.2) The average trip operating on the i-the graph. This speed was obtained based on the relationship between the arc length and the pitch difference between the initial node and final node. Where, V_i^a = speed (i) in the arc a (km/h); l_a = arc a length in meters; t_1 = pitch time in the initial node; t_2 = pitch time in the final node.

$$v_i^a = 3.6\frac{l_a}{t_2 - t_1} \qquad (2)$$

(Ec.3) The average temporal operational speed in the graph for a period of time. This speed was used to establish network resistance and was used as input to develop the forecasting model for the average trip time. Where V_a = average speed of operation of the arch; n = number of speed data registered in the arc for a given period of time.

$$\overline{v_a} = \frac{\sum_{i=1}^{n} v_i^a}{n} \qquad (3)$$

2.3. Calculation of the Global Accesibility Median

Analyzed from the vector of average travel time (*Tvi*), which represents the average time of trips from node i to other nodes on the network. This accessibility indicator tends to promote points located towards the center of a network because travel time from these nodes to other nodes is shorter due to their geographical location. An algorithm of the GIS was used, allowing for the calculation of lower resistance (shortest path) between a specific node and other nodes in the network, developing a uni modal resistance matrix. Through this matrix, and knowing the average operational speed of each, the matrix of minimum travel time average, which minimizes travel time between all nodes of the network, was determined.

Knowing the average operational speed of each arch, the matrix of minimum travel time averages was developed. Such model minimizes the average travel time between each and every one of the nodes that make up the network concerned. Once the minimum averages of travel were determined, the vector average trip time (*Tvi*, Ec.4) was obtained. Where, *Tvi* = minimum average travel time between node i and the other nodes in the network; t_{vi} = minimum trip time between node i and the other nodes in the network; *n* = number of nodes in the network.

$$\overline{T_{vi}} = \frac{\sum_{j=1}^{m} t_{vi}}{(n-1)} \quad i = 1,2,3,...,n \;\; ; \quad j = 1,2,3,...,m \tag{4}$$

The average retrieved travel time vector (n x 1) is associated with the geographical coordinates (longitude and latitude) of each of the node so as to develop a matrix of order (n x 3), which generates the isochronous curves of average travel times for the analysis of Global Media accessibility. The ordinary Kriging Method was utilized with linear semivariograms as a time prediction prototype for average trips. Six (6) analysis scenarios were defined: the first, average time of commutation in terms of Media Global Accessibility for the whole system, i.e., including the average operational speeds of all transport modes; the other five (5) scenarios are the average times of commuting, in terms of Global Media Accessibility for each of the investigated types of transport (car, taxi, motorcycle, truck and UPT).

2.4. Coverage Analysis

According to data provided by local authorities, the urban area of the city of Manizales comprises 35.1 Kim. The city has a population of 361.422 inhabitants (year 2010) with 83.868 households units. The information on population and number of housing areas was divided into the 115 districts that make up the city. Through the use of GIS, the average commutation time curves with corresponding demographic information were obtained for each mode of transport. This allowed the calculation of what percentage of the population area and number of homes was covered by a specific isochronous curve. Similar coverage applications occurred in other contexts (Straatemeier, 2008).

3. Main Results

The through street structure of Manizales is 620 Km long, is divided into the following manner: 9% principal, 9% secondary, 15% commuting, 46% local, 13% pedestrian and 7% semi pedestrian. The average operating speed, determined by the longitude of each category showed a direct relationship between the category of the route and the operational speed. For principals 34 Km/h., for secondary 23 Km/h., for commuting 19 Km/h., for local 14 Km/h. and for semi pedestrians 13 Km/h.. It is showed that these speed factors are based on actual data monitoring. For analysis of accessibility, a pedestrian’s travel speed of 2 Km/h. was assumed.

The average travel time curves obtained for the system (calculated with the average of all modes of transportation operating speeds) can be seen in Figure 2. It was found that the city is covered between isochronous curves of 25 to 70 minutes, showing that it is possible to traverse the city from one end to the other in a little more than one hour at the individual average speed proper of all the transport modes. In the same way a further expansion can be seen in the directional curves West – East, as well as in the North - South, pointing out that in this last direction, accessibility conditions are more limited, consistent with the topographic reality of the city. Each transport mode was studied individually, obtaining the average travel time curves for each one.

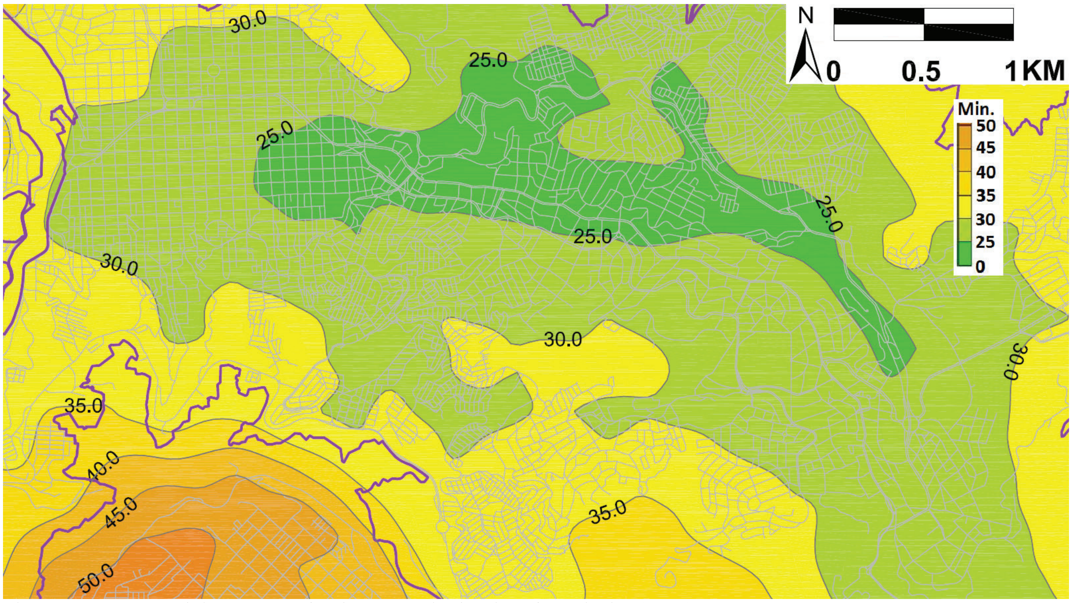
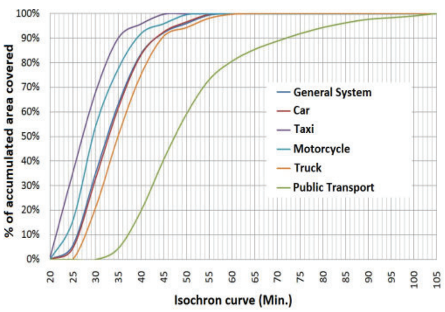
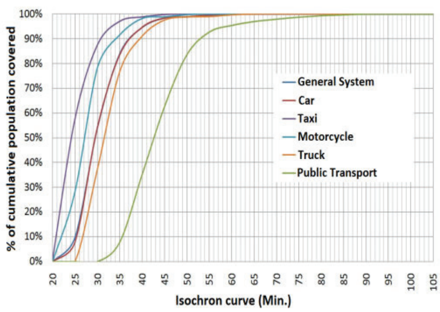


Fig. 2. Average travel time Curves for the system in the city of Manizales (2010) – CBD Sector.

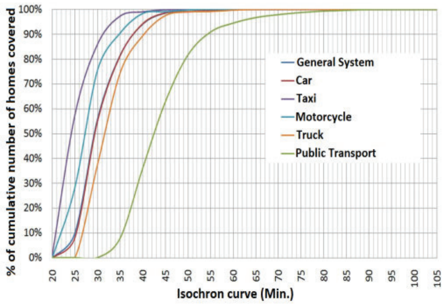
Linking the isochronous curves obtained for each studied scenario and with city demographic information distribution percentual curves of frequency for the variables of population and number of homes were also obtained. Figure 3 shows respectively: the percentage of cumulative area (a), the percentage of cumulative population (b), and the percentage of the number of homes on the isochronous curve. Greater slope curves encompass lower travel time percentages of average specific variables. Comparing the percentual curves of frequency for the area and population variables it is found that there exists a greater coverage of population in the urban area based on the average travel time, which is directly related to population density.



(a)



(b)



(c)

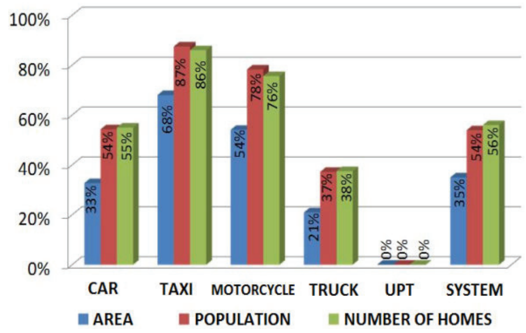
Fig. 3. (a) % of accumulated area covered; (b) % of cumulative population covered; (c) % of cumulative number of homes covered

It is determined that taxi and motorcycle modes show lower average travel times for the same percentage of coverage than other modes of transport indicating that these two modes are the most effective in terms of Media Global accessibility given the configuration of the existing street network. Evaluating the curve obtained for the system, it is possible to determine that 50% of the population is covered with average trip times of up to 29.5 minutes, while 50% of the urban area, and would be covered by average trip times of up to 32.5 minutes.

Figure 4 shows the percentages of coverage of the studied variables for an average travel time of 30 minutes (a) and 40 minutes (b), respectively. For 30 minutes of average travel time, the taxi mode covers 68% of the urban area 87% of the population and 86% of the number of urban homes, while other modes of transport involve smaller percentages of coverage. It is obvious that public transport was not included among variables for the average travel time. While the auto mode refers less favorable accessibility conditions than taxi and motorcycle modes, it accounts for more than 50% of the variable population coverage and number of homes, as well as 33% of the variable area values, even higher assessments than those obtained for the analysis of the overall system.

The percentages of area coverage, population and the number of homes for a 40 minutes average travel time,, are superior to 70% for all system transport modes of the system, except for the UPT,(in which such percentages reach 20% of the area, 35% of the population and 36% of the number of covered homes), hence highlighting its disadvantage in terms of overall accessibility with respect to other modes of transportation averages. It can be seen that the variable number of home units have a very similar behavior, in terms of coverage, to that of the variable population.

In order to emphasize the difference between mobilization by UPT or by car, the vector gradient of the average time was estimated as an average for the modified travel time. The vector gradient recounts the average trip time on UPT and by car, where the resulting value indicates what percentage of time must be spent in UPT with respect to time in the auto mode. The lowest ratio found was 1,6, and the highest was 2,6. The aforesaid indicates that the use of the public transport mode represents at least 60% more average travel time than that spent in a car. In the same manner, peripheral areas of the city were also sampled where 160% more of the average travel time must be spent.



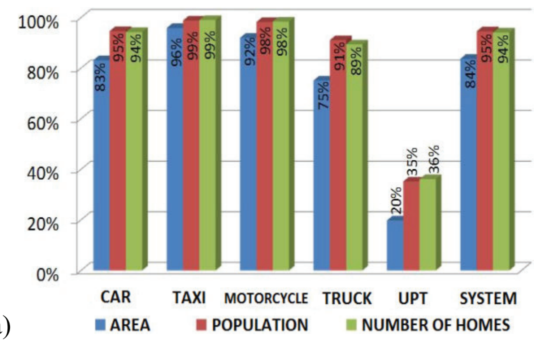


Fig. 4. (a) % coverage for 30 minutes; (b) % coverage for 40 minutes

Figure 5 shows an analysis of the accumulated percentage covered by the three variables (area, population and number of homes) with respect to the percentage of average travel time that must be employed utilizing car or public transport. It was determined that 100% of the three variables represent the necessity of spending up to 60% more of average travel time if UPT were employed; likewise, it is evident that approximately 10% of the population must spend twice the average travel time if the mobilization were done on UPT instead of auto. The latter values are considered high for a population of the characteristics of Manizales which demonstrates the great difference of mobilization given the operational and physical characteristics of each mode of transport.

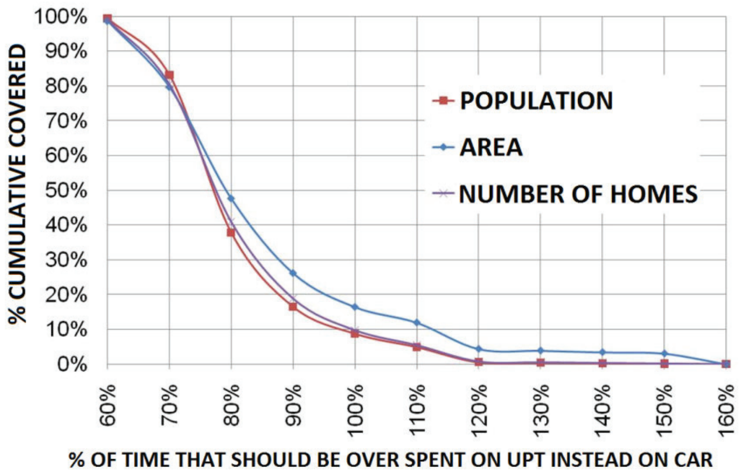


Fig. 5. Percentage coverage Comparison of revised variables, analyzed with regard to the percentage of time that should be spent on public transport, compared with the Auto mode.

4. Conclusions

The city of Manizales is enclosed amid isochronous curves of 20 to 105 minutes, which diverge according to the mode of transport used for the types of transport for the overall system. The expansions of the isochronous curves are outstanding in the West - East direction (towards the new economic development areas of the city), not so for the North – South direction. The curves open out along the West - East street corridor, following the ridge of the mountain on which the city lies. The accessibility analysis identifies the influence generated by the principal street corridors of the city and its urban areas as well throughout the average travel phases, considering that the operational characteristics of vehicle flows show evidence of functional deficiencies.

At the moment the method that offers optimal suitability of transport for Manizales, due to the special physical and operative characteristics of the street network is the taxi followed by the motorcycle, car, truck and UPT, in that order. The attained accessibility results demonstrates that there really is a social disparity with respect to the inhabitant`s mobility possibilities because the most widely used means of transport, is the most inadequate due to the characteristics of the average travel time. Based on such assumption it is necessary to establish policies for the UPT, providing better mobility conditions for low-income population which, unfortunately, has to use this mode.

Through the methodology used in this investigation, a thorough actualization of the network infrastructure of the city of Manizales was feasible, demonstrating the huge advantages of combining the use of GIS satellite monitoring technologies (GPS). It showed that real operating speed data was applied for calculating the isochronous curve, contrary to that used in the vast majority of accessibility analysis. It was found that operational speeds are faster for the principal streets than for low category ones, i.e. there is a well-defined relationship between the speed of operation and the category of the route. However, it was found that there some street corridors where functionality is not related to operational speed. In practice, functionality requires a very specific categorization in order to ensure that the aforesaid corridors are compatible with their true objective (Charlton et al., 2010), while drivers trough driving experiences commence to develop better knowledge of the sectional prototypes (Theeuwes and Godthelp, 1995).

The analysis of the diverse modes of transport on urban accessibility is considered to be a major step for defining the interventions that must be implemented in the city, considering that the enhancement of transport infrastructure turns is a key element for the economic development (Holl, 2007), allowing to overcome the dissimilarity in the social and habitat environments.

The accessibility analysis which is the focus of this paper involves the simple application of a database of real operating speeds augmenting the possibilities for implementing urban models in developing countries like ours. (Adhvaryu, 2010).

This is the first time that these kind of surveys are carried out in this city, taking into consideration that the GIS tools imparts a graphical interface that facilitates accessibility analysis. Recently these kinds of applications have gained popularity (Liu and Zhu, 2004) and can also be used to evaluate the changes in accessibility as a result of the development of transport infrastructures (Hou, 2011).

It is determined that this type of analysis provides a technical support that stipulates the accessibility conditions of a region, which at any moment can support decisions involving the alternatives that can be formulated for street network or transport systems in current use and above all, to establish in what areas of the city efforts can be unified to provide better ease of access for social mobility and to heighten the inhabitant´s quality of life.

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